Chapter 7

Developing Building Information Modelling for Facility Services with Organisational Semiotics

Bohan Tian and Haomin Jiang

Additional information is available at the end of the chapter

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Abstract

Built environment provides infrastructure and space that supports users' activities through facility services. Space provides the context in which services are constructed. Facility services management is facing challenges in information management that requires vast and heterogeneous information from design to operations of a building across various service systems. Building information modelling (BIM), an object-oriented modelling technology seeks to integrate information throughout the entire lifecycle of a building project. However, BIM is limited to meeting the needs of information arising from operation and management of facility services, and the requirements for BIM development are yet unclear. Though BIM building semantics can be enriched, but mainly focusing on building fabrics for design and build. BIM does not support the consideration of building operation activities and the context of building in-use. From a semiotic perspective, the lack of address in pragmatic and social aspects of a building project limits BIM as a through-life solution. This research deployed semiotics, a theory of signs, to analyse and develop BIM from an information system's point of view. Organizational semiotics is a sub-branch of semiotics, which offers a set of methods that can enhance BIM to link building fabrics to facility service activities.

Keywords: BIM (building information modelling), FM (facility management), OS (organisational semiotics), habitat

1. Introduction

The fragmentation within the construction industry is reflected in information and knowledge loss and process discontinuity during a building lifecycle. Such a gap between design/build and facility management (FM) results in an expensive and time-consuming process for data compiling and exchange into FM. Furthermore, a low level of interaction between specialist and facility teams transferring design intent and rationale, causing inefficient and ineffective FM. Building information modelling (BIM) is introducing a new form of information processing and collaboration for designing, constructing and operating buildings [1]. BIM has advantages in facilitating design and construction in the way of precise objectified description with 3D representation, and more dimensions such as 4D with time scheduling and 5D with cost estimating are integrated. BIM is also an entirely different approach of representing a building, which models an asset in digital form enabling those who interact with the building to optimise their actions and resulting in a greater value for the asset in the whole life cycle. The study of BIM for FM is an emerging area. A BIM-based FM model is a relatively new concept under exploration. Most research in the area has focused on enriching attributes of building components and their counterparts as building objects represented in BIM models from a design-and-construction perspective to describe building elements.

The challenge has generally been the capacity to provide information pertinent to managing facility service systems and to integrate operational information and construction information. Such capacity-making data more meaningful for decision support as 'intelligence' lies behind the services [2]. Facility services are operated and delivered according to personal preference and organisational policies in the form of rules or norms relating to allowed and desired behaviour of intelligent service systems [3]. Those features not only require integration of building information, technical engineering knowledge and understanding of the service process, but also the semantic and knowledge-based building information model with service processes. This research gap calls for BIM's development not only focusing on technical aspect, but also concerning social and organisational aspect of building spaces.

BIM has clearly shown value adding to design and construction. However, the current development of BIM is still largely centred on enriching building fabrics, whilst the links between building fabrics and facility activities are yet less addressed. An as-built model is more regarded as an FM model that is developed and applied in O&M (operation and maintenance) practice. But from the literatures we have learned that as-built models seem to contain information more in relation to repair and maintenance services, but less in addressing other services. Furthermore, there is little research linking BIM to FM service processes in a built environment. The context of use of a building is less addressed, hence services related to engineering information and knowledge are not reflected in BIM yet, which causes building information to be dissociated from the facility service delivery process. FM services deliveries are organised information-rich activities involving interactions between building systems, facility systems and user activities within organisations in a built environment. Thus, the requirements for developing a FM model are not only technical, but also rather social and organisational.

Within the background of BIM representing a paradigm shift in the AEC/FM industry globally as introduced above, this research is motivated by a problem of BIM development that arises in supporting the facility services management and accordingly meeting information requirements for services' operation and delivery. Consideration of BIM as a through-life solution for information management, there is a need of appropriate theories and systematic approach to develop BIM for connecting the D&B (design and build) and O&M (operation and maintenance), which enables FM managers to better understand how a building is operated and optimised.

Semiotics [4], as a well-established discipline of signs, offers a comprehensive theory to understand the nature and characteristics of signs and information system [5]. A sign is something, which stands out to somebody in some respect or capacity [6].

Organisational semiotics (OS), a branch of semiotics, facilitates the understanding of organisations as information systems through using semiotic methods. An information system can be interpreted and examined by organisational semiotic framework [7] at six semiotic levels, which are social, pragmatic, semantic, syntactic, empirical and physical levels. A building as a sociotechnical environment and its virtual representation as BIM is a complex sign system that allows stakeholders to utilise, interpret and interact with. BIM can partially overcome identified semantic and syntactic issues in FM [8]. However, BIM has yet to support business process with the consideration of building activities and the context of use [8–10]—i.e. lacking pragmatic and social aspects from a semiotic perspective, which limits BIM as a through-life solution. Therefore, the major research question is addressed in this study: can organisational semiotics (OS) be used to bridge building information modelling (BIM) making a focus of building fabrics and facility management activities concerning with the service management.

The next section is organised in three parts as followings: first, the theory of habitat and organisational semiotic framework are adopted to analyse a building from a semiotic perspective, addressing the features identified for a habitat, which provides interrelated contexts for facility services management. Second, the following section deals with specifying service-related information requirements based on the analysis of the habitat. The last a summary is provided.

2. Theoretical foundation: a semiotic perspective to service-oriented built space

This section makes the suggestion to the research question. The process of constructing the solution is by obtaining a general and comprehensive understanding of the problem and followed by a theoretical analysis. Buildings are regarded as special and complex products that provide functional spaces enabling people to live, work and achieve their goals. So, a building can be featured as a sociotechnical system. The research regards a building as a complex sign system. BIM is used to model such sign systems from a semiotic perspective. Semiotics, the discipline of signs, provides a solid theoretical foundation for stakeholders' understanding of the characteristics of sign-based and service-oriented built environments. Semiotics offers a series of theories and approaches to underpin this research for deriving information requirements and modelling facility services from a semiotic perspective.

2.1. The theory of habitat

A built space can be treated with the notion of 'habitat' [11], which is depicted by three types of habitats from a semiotic perspective. The term 'habitat' originates from biology, and it is defined as an area that has all that is needed for survival of a species.

The habitat was introduced as a design metaphor by May et al. [12] to study the requirements arising from information systems become embedded in the physical environment.

For a built environment, Andersen and Brynskov [11] define a habitat as an environment that supports and mediates the activities of its inhabitants, presents a set of affordances. A habitat is described from three different features: physical, informational and pragmatic dimensions.

The physical habitat is made of physical space with a defined layout and boundaries over time, i.e. three physical dimensions plus time. The physical habitat is tangible such as a kitchen in a house or an office. People can do their work in offices such as reading, writing or typing and so on, and the physical habitat addresses how interactions between space and users are dynamic over time. For example, a new facility can be installed if it is required for users' activities. A moveable partition wall in between two rooms can be moved to expand spaces if users require a large space for their activities. Different activities can be arranged in the same room over time such as a meeting or a lecture occurring in a multi-purposed designed meeting room. Furthermore, physical habitats can be nested. A given example is a train: the train as a whole is a habitat for travelling activity (embarking, showing tickets and disembarking), but as a part of a train, the compartment is a habitat for work activities. Regarding the built environment, an office building contains spaces with different functions.

The informational habitat is a well-defined combination of information and media that support certain inhabitants' information and communication needs. The informational habitat is essentially semiotic by nature and involves a process of communication and interpretations. The informational habitat provides signs available to participants in the activities through the use of digital and non-digital signs. Informational habitats are distinguished between the representing part and presented part. The representing part is an access area where the inhabitants have access to the information, while the reference area is the object of the information. For example, an exit sign is understandable to users as it clearly indicates the way out.

From Bynskov and Anderson's description, we know that pragmatic habitats concern the social aspect of a space, i.e. inhabitants have their expectations and intensions of using a space, which is closely associated with users' activities. The potential activities exist as different stakeholders' goals and expectations, or regulations and rules that result in certain behavioural patterns. In addition, inhabitants may need to have knowledge and skills for using facilities and taking part in activities in a built space. For example, in a hospital, inhabitants such as doctors and nurses have their knowledge and certain activities that will occur in their workplace. Their activities are also governed by organisational norms. Furthermore, the members of a potential pragmatic habitat are the inhabitants, who could be people, as well as digital agents that have capacities to perform and meet requirements. For example, HVAC equipment could be a digital agent that can condition a room when needed.

2.2. A semiotic perspective to the habitat

In operation and maintenance stages of a building, built spaces support users' activities through facility services. Thus, the value of the built environment is realised through the services it offers and interactions that it mediates and enables for people. The built environment provides users an infrastructure and space in which service contexts are constructed. Service is a rather abstract concept; however, facility services can be presented and understood properly if whole building context is considered. The three types of habitat as effective approaches to identify the building contexts are associated with facility services.

The OS framework provides an approach that systematically concerns the use of signs. From a semiotic perspective, a building or a habitat in this research is a complex sign system that has its meanings. By using the OS framework, we can analyse the aspects of such sign systems and their effects on facility services. For this research, the result of analysis can guide us to derive information requirements for modelling services in a built environment. Based on the theory of habitat, the habitat can be further extended and characterised by a combination of physical, temporal, technical, informational, empirical, syntactic, semantic, pragmatic and social aspects, which are all associated with the representation of facility services (**Figure 1**).

Spatial flexibility affects services, too. Two spaces can be combined into one large space by removing the partition wall between them. The change expands the space's volume so that it can contain more people to do something that a small space is not able to offer, e.g. a gathering or a party that simply requires more space. Such change enables more spatial affordances. Consequently, facility services may change correspondingly to meet the requirements arising from the new functions. For example, ventilation's capacity increases to provide more fresh air, and fire evacuation routes may change to meet the regulation. Equipment and devices, as well as furniture arranged in a built space, also indicate certain services. For example, medical devices installed a differentiate ICU (intensive care unit) and a general ward that have different specialist services. In a flexible meeting room, chairs can be rearranged to fit the type of meeting. They can be lined up for a presentation, or placed in a circle to promote discussion. It is worth mentioning that devices and equipment that belong to service systems are a technical aspect of a habitat. These objects provide technical context for services.

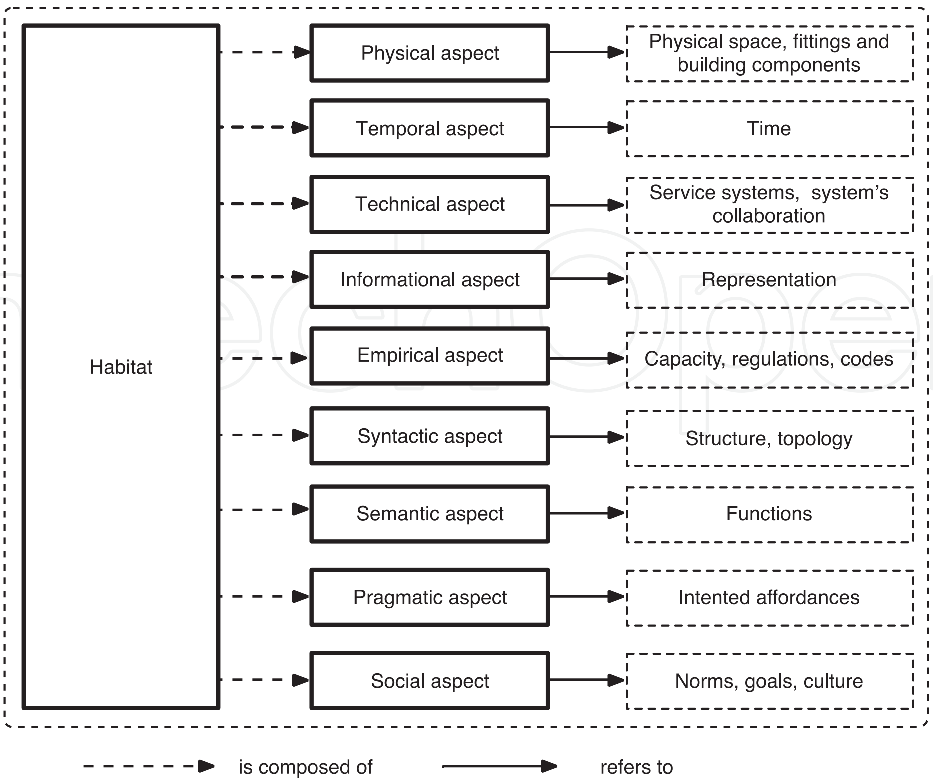

Figure 1. Habitat deconstruction from a semiotic perspective.

A habitat is also characterised by the temporal, which is closely bonded with a physical space. The time change over a built space affects services as well. Lighting configuration may be different for a building between working-time and off time from energy conservation or security perspectives. A high level of space utilisation in a workspace is defined as a space used for the maximum possible amount of time. Second, a built space is usually managed and used over time. For example, a meeting room is managed according to schedules. Building systems are configured to serve a built space in line with space schedules (e.g. work-hours and off-hours, or daytime and night-time). Facility service management often takes into account the spatial and temporal aspect (e.g. a seminar room is scheduled with different events that require different services).

The habitat has technical character. A building provides users with various services, and requires many buildings or facility systems to function. The supporting systems including building systems are integrated, which allows interaction and coordination between them so there is interoperability. The IB (intelligent buildings) approach enables various service systems to be managed and controlled in an integrated manner based on a sensor network. With rapid development of control systems and communication networks, occupants are expected to have more control and interactions with enhanced spaces, which are called intelligent pervasive spaces [13], or alternatively defined by Nakata and Moran [14] as 'an adaptable and dynamic area that optimises user services and management processes using an information system and networked ubiquitous technologies'.

The habitat is characterised by informational factors. Building operation is achieved through interplays between the buildings and people. A building is full of signs that provide information for people to interact with. From the layout, decoration and equipment of a room, it enables people to know whether it is an office or a patient ward. There are instructions available for people to understand how to use a building. A simple example is a thermostat or a programmer in a space that might indicate that the room has air conditioning services and the occupant can adjust the temperature manually. Furthermore, the information provided and its perception and interpretation is subject to a person's knowledge. Occupants ought to leave the building immediately when they hear a fire alarm beeping which indicates a fire has occurred, with an exit sign guiding people to evacuate. For some facility services, some building elements may link to other information sources for sense making. For example, a security camera records videos to monitor a certain built area, and the data are stored and linked to somewhere else. The recorded videos are meaningful for securities. A smart metre records building performance figures, and the accumulated data can be useful for performance analysis for facility managers or energy officers.

The habitat has an empirical character. Empirics are a branch of study of the statistical properties of signs when different physical devices are used. In the design and construction area, the empirical level is concerned with building architectural and mechanical designs that need to not only meet design specifications, but also comply with regulations and codes. For example, the capacity of a disabled toilet needs to meet certain standards in dimensions and facilities to assist the disabled for use and convenience. Other parameters of artefacts that empirics deal with may be spatial capacity, designated lighting brightness, lift capacity, HVAC (heating, ventilation and air conditioning) capacity, etc.

The habitat has syntactic features and concerns the rules of composing complex signs from simple ones. In the design and construction field, the syntactic level represents the requirements of topology of space and building systems, i.e. the layout of space and the logical relationships between building system elements. For facility service management, the syntactical aspect is crucial for understanding service system composition and each component in the system, such as devices, sensors or the controller's roles and effects. It is important to interpret engineering system diagrams to information models for facility service management.

The habitat is characterised by semantics. Semantics is the study of the relationship or interactions between a sign and what it refers to. The semantic level concerns meanings of built spaces and artefacts present within them. A space needs to be socially and physically defined for its functions and purposes, which are supportive for business activities. Built spaces provide the context in which services are constructed. Such service context concerns in building use are constrained by limitations in a physical space.

The habitat is characterised by pragmatics, and this concerns the utilisation of a specific space in detail, which involves occupancy patterns, services invocation, and norms and regulations in the service process. Occupancy pattern is referred to as the intended use of a space and possible activities. For example, a multifunctional room is designed to have more occupancy patterns that can satisfy various users' needs. In this case, the service systems of the room can be configured for multiple sets of preferences according to its usage. For instance, service attributes of a normal working scenario can possibly differentiate temperatures and lighting levels from a meeting scenario. In this case, the service systems of the room can be configured for multiple sets of preferences according to its usage. Moreover, a particular occupancy pattern may require related services to support users' activities.

The habitat has social character. The built space provides a physical ground on which social spaces are constructed, with the social space constituted by cultural settings, relationships and interactions between people that are dependent on physical spaces. A social space may regulate how people use a built space. Therefore, it may enable or inhibit affordances in a built space. For example, a social space may prevent occupants opening windows when air conditioning is on for the consideration of energy conservation. Building types and organisations occupying the space affect people's behaviours, for example, at a hospital or university. Certainly, there are differences in how people interact with the physical spaces and also the interplay between people, doctors and patients, or lecturers and students. Even the same building type, for example, office buildings, may have different enterprise cultures and correspondingly norms in an organisation that affect interaction between people and built spaces differently. Google's open culture shapes its workplaces unusually with more open planning, and more interesting decoration, which this tech giant believes has a positive impact on productivity and collaborations and inspiration, while other organisations prefer traditional cubicles in their plan.

2.3. Illustration of the habitat

In the last subsection, a habitat is analysed and deconstructed from a semiotic perspective, which contributes to our understanding of the relationship between such enabling built space and services. A habitat is demonstrated as a combination of nine semiotic-layered aspects. Two examples, a seminar room and a hospital ward, are given to illustrate each habitat aspect related to services in this subsection (**Tables 1** and **2**).

Habitats aspects	Description
Physical	Building components, e.g. walls, carpets, windows, doors
	Furniture, e.g. desks, chairs, shelves
	Equipment, e.g. computers, projection screens, projectors
Temporal	Service schedule, e.g. cleaning 6:30–7:00 am; HVAC 8:30 am–5:00 pm
	Room schedule, e.g. meeting 9:00–10:00 am
Technical	Service systems and collaboration, e.g. BMS, room booking and timetabling, services process
	System components, e.g. smoke detectors, fire alarm call points, CCTV cameras, Wi-Fi extenders
Informational	Utilisation of facilities, e.g. signage, service instruction, policies for users
Empirical	Capacity of facilities, e.g. lighting brightness, air conditioning capacity
Syntactic	Department, spatial structure, service zone
Semantic	Services profile, e.g. lighting, HVAC, CCTV, fire protection, parking, room booking, cleaning, catering etc.
Pragmatic	Seminar, users, e.g. lecture and students
	Meeting, e.g. staff, students, visitors
	Gathering, e.g. staff, students
	Invigilation, e.g. students, invigilator(s)
Social	Specific rules for the use of the room and related services

Table 1. The description of habitat aspects for a seminar room as an example.

Habitats aspects	Descriptions
Physical	Building components: walls, carpets, windows, doors
	Furniture: ward beds, wheelchairs, chairs
	Equipment: medical devices
Temporal	Service schedule: cleaning 8:30–9:00 am;
	Room schedule: visiting 2:00–8:00 pm
Technical	Service systems and collaboration: BMS, a hospital ward management system, visual systems, service processes
	System components: smoke detectors, lighting, nursing call points, CCTV cameras
Informational	Utilisation of facilities: signage, service instructions, policies for users
Empirical	Capacity of facilities: lighting brightness, air conditioning capacity
Syntactic	In-patient department, spatial structure, service zone
Semantic	Services profile: lighting, HVAC, CCTV, fire protection, nurse calls, medical gas, car parking, in-patient
Pragmatic	Care and treatment: patients, medical staff, visitors
Social	Medical device management policy, hospital ward management policy

Table 2. The description of habitat aspects for a general hospital ward.

With two examples illustrated as followings, the semiotic aspects of a habitat pertinent to facility services are summarised as follows:

- The physical aspect of a habitat refers to physical spaces and building components maintenance, which are mostly related to location identification and facility maintenance.
- The temporal aspect of a habitat considers the time of using a room, which affects the time and sequence of service deliveries.
- The technical aspect of habitat concerns.
- The informational aspect of habitat concerns with information or signs, which can a guide and instruct users to operate facilities.
- The empirical aspect of a habitat describes the capacity of building elements including built space, systems, and devices, which may affect service deliveries.
- The syntactic aspect of a habitat describes structural elements in relation to facility services.
- The semantic aspect of a habitat indicates the functions of a built space, which may decide the required services to support intended users' activities.
- The pragmatic aspect of a habitat describes the intended affordances (intended user activities) and related users. The knowledge and skills of users to operate the facilities are also considered in this level.
- The social aspect of a habitat includes organisational policies and norms, which provides reference for the configuration of rules to service deliveries.

2.4. Habitat-centric service information requirements

Service-related information is required in order to support the facility service delivery process. The BIM-based facility service model is aimed at providing information that is potentially consumed by facility management (FM). The habitat provides the context in which the services are constructed. The features identified by the semiotic approaches in the last section have addressed different aspects of a habitat, in which service-related information can be derived. Specific information requirements are presented by analysis of the habitat in relation to facility services. As a result, the BIM-based facility service model can serve as a pre-set service context to assist FM. The context information can be classified, within the scope of the work, into four principle sets, which are user dimension, physical dimension, technical dimension and service dimension. The multiple service-related dimensions reflect the identified factors of FM discussed in the previous subsection. Each dimension is a collection of reference information for supporting FM activities (shown in **Figure 2**). In turn, the habitat sheds light on specifying the information content of each dimension in a FM service context. The interrelation between each service-related dimensions and habitat aspects, as well as dimensional information requirements, is illustrated in the following subsections.

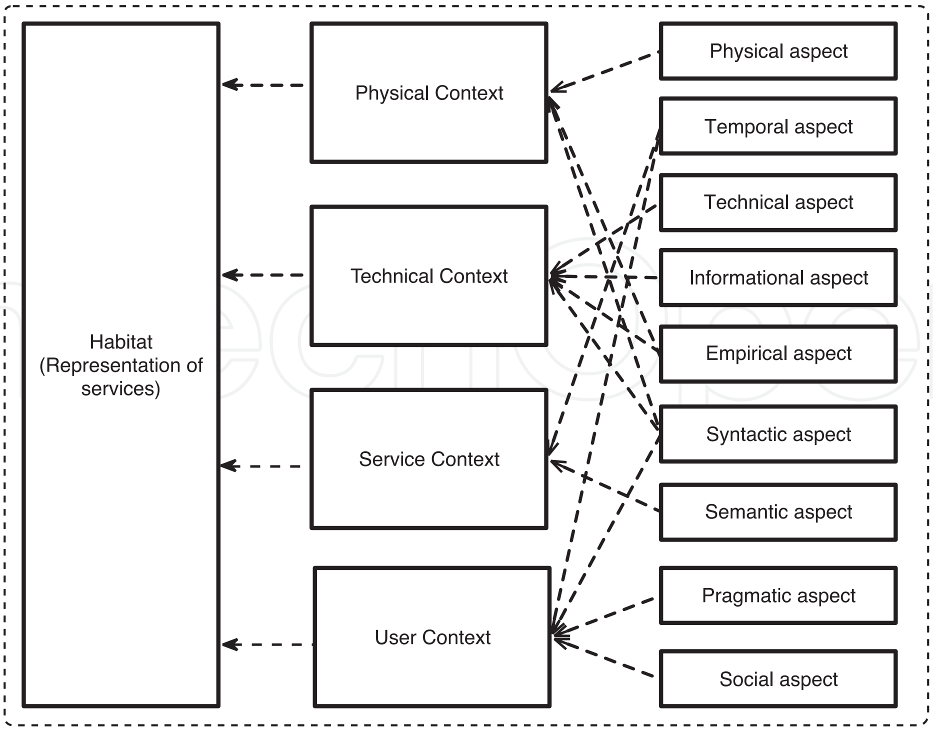

Figure 2. Interpretation of the habitat into categorised service-related dimensions.

2.4.1. User dimension

The user dimension refers to the information related to users' activities of a space. The user dimensional information not only affects how a building is designed in terms of space layout, decoration, furnishing arrangement and building systems, but also is required for multiple FM services systems in their daily activities. A certain habitat (a building type) implies who are the users, their activities or patterns, and their knowledge of supporting intended activities. For example, a hospital's users are mainly medical staff such as doctors and nurses, and patients. In a university building, the main users are faculty staff and students. In the building operation and maintenance stage, users' patterns of their activities affect what and how facility services are delivered.

The content of user dimension is concerned with the pragmatic, social, syntactic and temporal factors of a habitat. The pragmatic habitat constitutes the affordances offered by the habitat and the possible actions or behaviour enabled within the physical habitat [15]. Users' activities in a habitat are defined in the user dimension, considering a space can have multiple functions and can be arranged for different sessions or events over a given time span. Thus, their service requirements for different utilisation of a space can be discussed and linked with defined activities. Users or occupants can possibly have multiple sets of preferences specifically responding to the change in the utilisation of their physical environment. For instance, it is possible to specify different temperatures and lighting levels for a customised personal working environment compared to that for the use of a meeting. In addition, a pragmatic habitat also concerns a user's knowledge or is able to follow informational instructions to use facilities, which is included in the dimension.

However, the affordances that users' activities may be constrained by the social habitat. For example, a norm indicates that a user may not be allowed to open a window when the air conditioning is working for the consideration of energy conservation, although the user is able to open a window that is supported by a physical habitat. A library or a room may not allow food and drink to be brought in. Hence, the pragmatic and social habitat can serve as enabler or inhibitor to users. The social habitat refers to the information related to organisational policies, their objectives and building performance benchmarks in terms of FM services, which can be interpreted and coded as norms to guide service deliveries.

A temporal habitat normally linking with users' activities indicates temporal patterns. The information can be pre-set according to use patterns of a space or a building, which particularly benefit from the configuration of BMS to automatically control building with concerning energy efficiency, or simulation and prediction of energy consumptions of a building. In addition, the information can be available from service systems such as the booking or time schedule system, and to be linked with a particular space in BIM-based information model.

A user can be an organisation that occupies a building or a group of spaces; or an individual person who occupies a space; or a group of people who share a space together. The syntactic habitat for the user dimension concerns organisational structures. The information is required for the configuration of a number of service systems such as space management, move management, as well as considering controlling norms for BMS. An individual user's profile may include the user's name, organisation (department), occupation and personal preference of a service and so on. An organisational profile may include name, business type and organisational policies. With user dimensional information being developed and stored in a BIM model, designers and engineers can specifically configure facility management systems such as BMS to deliver services according to users' preferences for specific activities in a built space. User dimensional information requirements are demonstrated in **Table 3**.

Dimension	Habitat aspects	Specified dimensional information
User dimension	The social aspect	Benchmarks that measure services concerning organisational objectives
		Norms that can be coded into FM systems and processes to control service deliveries, which are derived from organisational policies, objectives and rules, or building regulations
	The syntactic aspect	The hierarchy of an organisation, e.g. organisation—department—group—person
		Priority of implementing norms for service deliveries, e.g. organisational rules > group preference > personal preference
	The pragmatic aspect	Sessions (user activities) based on spatial functions, e.g. meetings, seminars, events
		Users who are associated with a specific profile, e.g. organisational rules, policies; personal preferences; or a person's role or occupation with indicating appropriate knowledge or skills to conduct activities
	The temporal aspect	Temporal patterns related to users' activities in a space

Table 3. User dimensional information requirements in the habitat.

2.4.2. Physical dimension

The physical dimension is about information related to physical spaces and building components. It mainly deals with the physical character of a habitat. According to Anderson and Brynskov's definition, the physical habitat consists of the physical layout and boundaries with the available physical artefacts [13]. The physical dimension describes a built space by three physical dimensions, its position in a whole building, and building components attached to the space such as doors and windows. Furthermore, the physical dimension is also concerned with building materials and fittings that fit building functions. It is worth mentioning that system devices and equipment are categorised into technical dimensions, which are addressed as the technical factor of a habitat.

Representing spatial structure also involves syntactical character of a habitat, which indicates physical relations between spaces. Building components are constructed as objects to represent their counterparts in the buildings in the BIM model. It is recognised that representing the physical character of a habitat is widely applied and required for a wide range of FM services, particularly important to the repair and maintenance service. We can conclude that the physical dimension is often the focus of an as-built model and can be compiled from the as-built model. A facility service model is built upon this as-built model, which is extended to represent a habitat by adding other identified service-related dimensional information. Other service-related dimensional information can be linked with a physical space by defining relationships between objects with BIM intelligent object modelling technology. The physical dimensional information is presented in **Table 4**.

Dimension	Habitat aspects	Specified dimensional information
Physical dimension	The physical aspect	The space and its boundaries, e.g. walls ceilings Other building elements within the space, e.g. doors and windows, or other elements defined in relation to a specific service e.g. repair and maintenance
		Furnishing and layout, e.g. desks, chairs, or appropriate types of furniture
	The syntactic aspect	The spatial structures, e.g. building—floors—spaces
	The empirical aspect	Spatial capacity, e.g. area, regulated or designated accommodation of people

Table 4. Physical dimensional information requirements in the habitat.

2.4.3. Technical dimension

The technical dimension refers to the information about descriptions of service systems and constitutive devices. A building itself is not only an aggregation of spatial elements but also an assembly of building service systems. On the system level, the technical dimension concerns building services' system topology and system coordination, which addresses the relationships between devices and systems, respectively. Building systems' components are modelled to connect with each other in an as-built model to show their physical relationships. In service models, a building system topology indicates logical relationships among devices and instruments, which indicates their impacts and roles in a system. Service systems' key components with input/output functions such as actuators, sensors, or metres are modelled to show their logical connections and functions in the systems. Technical dimensions deal with technical and empirical character, as well as the syntactical and informational character of a habitat. The technical dimensional information is presented in **Table 5**.

Dimension	Habitat aspects	Specified dimensional information
Technical dimension	The technical aspect	System integration and coordination, for service delivery to facilitate user activities, e.g. defined service processes
		Device functions, e.g. input/output protocol for real data exchange, virtual addresses
	The informational aspect	Service instructions to users, e.g. exit signage, audio and visual alarms, visual or textual guidance to facilitate user activities
	The empirical aspect	Device and equipment capacity, e.g. lighting brightness, ventilation air flow and volume
	The syntactical aspect	System topology, e.g. service zone, loop, circulation

Table 5. Technical dimensional information requirements in the habitat.

2.4.4. Service dimension

The service dimension refers to information about facility services related to a certain user activity or occupancy pattern in a space. The service dimension deals with the semantic and temporal aspect of a habitat. According to the review, we understood that the facility services can be various including building services such as HVAC, lighting and fire protection services, but also other 'soft' services such as car parking, a room booking service, energy management and so forth. In the context of building operations, a space may have multi-functions, which afford different activities that are in need of specific services to support. Which services are designed and required for a building needs to be defined in the design and commissioning stage. For example, an office may offer lighting, HVAC service and video conferencing service in a meeting session, as well as fire or security service in an emergency event.

Service dimensional information helps to define and configure service profiles for an integrated FM service system to manage a building in use with timetabled sessions. Specific services can be grouped and linked to a space with concerning use patterns of it. In addition, supporting system and devices can also be defined to link different services in a building with smart IP-based sensor networks. Furthermore, a service (e.g. maintenance, cleaning) may be required to link with physical artefacts including components and devices if it is necessary. A facility service such as a cleaning service is needed as one form of maintenance for the entire building fabric during the operational life of the building. The doors, windows or floors and rooms will require cleaning from time to time. Building information models can be a fortified database of a building to represent building elements or space that requires cleaning. More than that the data attached to the elements can provide dynamic information of the cleaning status and static information about cleaning specifications and requirements.

Service dimension also includes basic descriptive information such as service contractor, service supplier and service requirements, or specific service operator, manager for a particular area of zone to demonstrate such an abstract concept, according to facility manager's requirements. Different services defined in the service model may have various services. In BIM-based modelling technology, those information may be presented as spatial attributes attached to a space object. A space object is represented with containing dimensional information in a habitat to meet different service requirements. HVAC service uses space to represent sensor and controller's location and occupiers' preference of the space. Timetabling service uses the space with its room schedule. Space management service is to define where staffs are located. In maintenance service, space is used to indicate a geometric space in a spatial topology. For example, the operation of BMS requires information such as room location and room schedule, as well as user's preferences, which can be pre-configured during design or commissioning phase. The service dimensional information is presented in **Table 6**.

Dimension	Habitat aspects	Specified dimensional information
Service dimension	The temporal aspect	Time schedule of a room for invoking services, e.g. a meeting
		Time record of an emergency event, e.g. fire event
	The semantic aspect	Facility services that are required to support a specific user activities e.g. the service profile of a room
		Descriptive information includes Service supplier, contractor, requirements and so on

Table 6. Service dimensional information requirements in the habitat.

2.5. Discussion and conclusions

The purpose of this chapter is to define a theoretical foundation for understanding and analysing a building, which is treated as a sociotechnical sign system. This chapter has set out to investigate service-oriented habitats from a semiotic perspective. Organisational semiotics is suggested as the appropriate theory to bridge the gap between building fabrics and FM activities for BIM concerning with the FM service management. Analysing and deconstructing the built environment into multiple service-interrelated characters (the physical, temporal, informational, technical, empirical, syntactic, semantic, pragmatic and social) from a semiotic perspective contribute to the derivation of information requirements on the basis of treating the built environment characterised as a service-oriented and sign-based habitat.

To the field of BIM for FM, the Habitat-centric approach is used to develop a domain-specific information model that specifies the nine habitat aspects linking to four types of FM service-related information. These are user dimension, physical dimension, technical dimension and service dimension, to satisfy information requirements for facility service management.

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Theoretically, this novel approach, inspired by Organisational Semiotics, systematically associates physical aspects with the pragmatic and social habitats considering user activities in a built space. Practically, it enables BIM as an integrated data model to support various facility services and system integration and collaboration between them in daily FM operations. Specifically, the BIM-based facility service model with integrated information can be used to demonstrate service classes with their attributes and relationships, as well as service process with norms. The model contains required information to configure separate service systems or serve as an integrated data model linking with real data model from different sensors to assist decision making to prioritise building performance with a consideration of user activities. Through the modelling development, the facility service model provides a service-oriented approach to connect and identify necessary building elements based on facility service deliveries. Specific elements or different habitat factors can be identified in relationships within a facility service delivery process, for example, occupiers, devices, space, process and norms.

Each building element linking with facility systems can check the relevant habitat information to the service process. For example, for a teaching space such as a seminar room, not only the spatial scale and use rules can be checked to assist booking system (user number constraint or catering constraint), but also the available teaching equipment in a space can be listed, if specific equipment needs IT (system) support for configuration before the teaching session. BMS systems cannot only check room-booking timetable data linked the space in the service model for any scheduled information for energy conservation, but also can request norms from the service model as instructions to deliver HVAC, lighting or other services to satisfy specific users' requirements. Repair and maintenance service can check maintenance information on the devices to make sure the device is operational when it is in use. The users' profile can be checked if they have required knowledge or certificate to operate facilities in some situations, e.g. invigilation requires trained invigilators. The use cases can be defined and extended according to specific building projects and FM systems requirements.

The facility service model though is intended to address pragmatic and social habitat to demonstrate facility services, compared with as-built model, physical aspect of a habitat is also included. The habitat factors are interrelated and a relationship between building fabrics and human factors is essential to enrich and describe facility service from an engineering and practical perspective. Furthermore, the Habitat-centric approach can also be applied in an iterative BIM development process of integrating service-related information including building fabrics and human factors. The BIM-based facility service model will keep developed until required information is complete to fit FM system during a whole lifecycle of a construction project.

Author details

Bohan Tian[1]* and Haomin Jiang[2]

*Address all correspondence to: tianbohan@gmail.com

1 Future Information and Control System Centre, Brighton, United Kingdom

2 NBIMer Technology, Beijing, China

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